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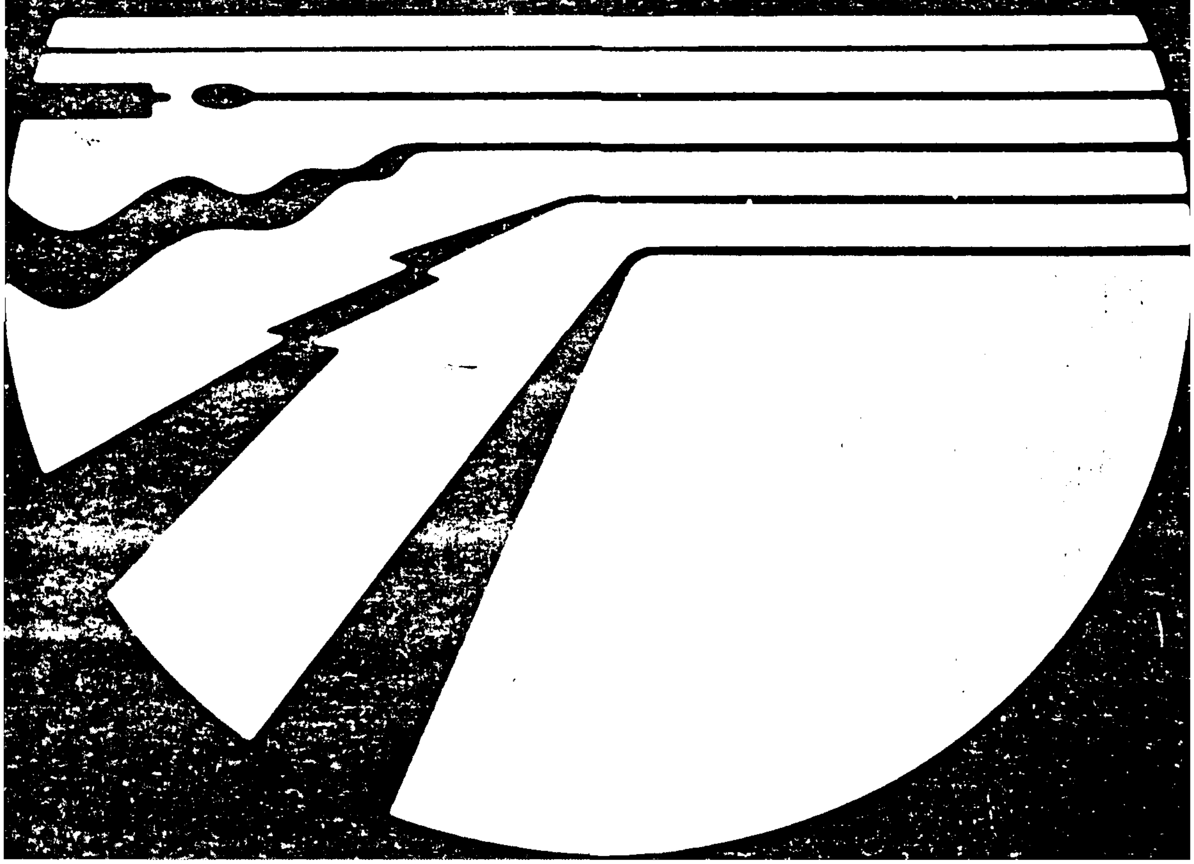

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REPRODUCTION OF CUSTOM COLORS FOR THE NAVY'S COMPRESSED AERONAUTICAL CHART

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ABSTRACT

This paper presents a procedure that is used to reproduce custom colors on color hardcopy. The set of custom colors is comprised of red, green and blue (RGB) intensities, where intensity levels range from 0 (no intensity) to 255 (maximum intensity). The hardcopy device that produced the results in this paper normally transforms RGB colors into cyan, magenta, yellow, and black (CMYK). However, adding black ink during the printing process tends to cause the loss of some low-intensity colors and an overall graying of the output image. This phenomenon has been termed "color drop-out." The procedure described in this paper eliminates color drop-out in custom color reproduction by omitting black ink. This approach more accurately reproduced custom colors for the data set used in this study. Two other less successful methods are also presented.

INTRODUCTION

The Navy is developing a database of scanned aeronautical chart images, the Compressed Aeronautical Chart (CAC), for use in aircraft digital moving-map systems and for mission planning.[1] The CAC uses a set of 30 custom color palettes. Each palette consists of 240 distinct colors, and each color is comprised of RGB intensities. Intensity levels range from 0 (no intensity) to 255 (maximum intensity). Although the CAC is primarily destined for video display, the need for high-resolution color hardcopies also exists. Available plotter hardware and software produced unacceptable colors, since the low intensities of certain CAC palette colors resulted in poor color reproduction in hardcopy. Low-intensity palette colors suffered from color drop-out, which tends to produce colors with a gray-shade appearance. It was discovered that color drop-out is caused by addition of black ink, which is specified by the plotter software. Some color hardcopy devices produce black by blending the three primary inks (RGB or cyan, magenta, yellow (CMY)). However, this process often results in a somewhat muddy black. This problem has been solved for other devices by using black ink to produce true black. These devices also add black ink to colors other than true black which, when combined with the subsequent reduction in the CMY intensities for those colors, can produce the graying effect of color drop-out.

This paper presents a procedure that eliminates color drop-out and reproduces custom CAC palette colors that are comparable in quality to the colors found in original aeronautical charts.

PROBLEM DESCRIPTION

The custom color palettes for CAC data are based on intensities of the additive primary colors: RGB. The in-house, high-resolution, color plotter hardware, which relies on the complementary subtractive primary colors, CMY, produced plots with unacceptable colors. In particular, the lower intensity colors suffered from color drop-out which, as previously described, resulted in a gray-shade appearance (Fig. 1). Higher intensity colors suffered less from color drop-out but still did not reproduce well.

CAC RGB intensities are normalized for use with conventional display devices by using the following algorithm:

$$\begin{aligned} R &= R/255.0 \\ G &= G/255.0 \\ B &= B/255.0\,. \end{aligned} \tag{1}$$

The in-house plotter plots CAC data by first converting the normalized CAC RGB intensities to their CMY equivalents. The following transformation[2] is used for converting from RGB to CMY:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{2}$$

CMY values are adjusted to reflect the plotter's addition of black ink. The adjustment algorithm[2] uses black in place of equal amounts of CMY as follows:

$$\begin{aligned} K &= \text{minimum}\,(C,M,Y) \\ C &= C - K \\ M &= M - K \\ Y &= Y - K. \end{aligned} \tag{3}$$

Using a 4 × 4 pixel pattern, CMYK inks are deposited on paper as a grid of colored dots. The orientation of each colored dot allows the eye to spatially integrate light that is reflected from adjacent dots. For any given CMYK component, a 7% minimum intensity is required to have at least 1 element activated, out of 16 in the pixel matrix. CMYK components with intensities of less than 7% (i.e., no color) will not be plotted. The following algorithm[3] is used to calculate the number of elements (within the matrix) to activate for a given CMYK intensity:

$$\text{Number of elements} = (\text{intensity} * \text{matrix size}) / 100 \tag{4}$$

where intensity = (intensity * 100) + 0.5
matrix size = 4 × 4 elements.

The CAC palette has been sorted by increasing intensity. As shown in Fig. 1, color drop-out was most severe; in the lower intensities. One attempt to alleviate color drop-out was based on the hue, lightness, saturation (HLS) color model,[2] in which the CAC color palette was shifted toward white along the achromatic axis to increase the overall color palette intensities (Fig. 2). This achromatic shift succeeded in producing less color drop-out in lower intensity colors. However, the shift resulted in the opposite problem: lighter intensity colors were "washed out" (i.e., too much white). Applying a combination of achromatic shifts to individual colors was deemed undesirable due to the significant number of color palettes that would have to be modified. Even with the availability of examples of computer-generated colors,[4] where percentages of each CMYK ink are provided, there are simply too many individual CAC palette colors that would have to be matched.

Another attempt to alleviate color drop-out involved increasing the pixel pattern to 8 × 8. The procedure required, a minimum intensity of 2% for any given CMYK color to have at least 1 element activated out of 64. This attempt also proved to be unsatisfactory because although the resulting plots had less color drop-out, they suffered a gridded appearance due to the orientation of colored dots within the matrix.

An underlying problem with both of these approaches is the large number of colors that requires manipulation (240 colors in each of the 30 standard CAC color palettes). Rather than working with every color in a given palette, a test palette was devised. Since CAC data is comprised of RGB intensities (which are later transformed into their CMYK components), various intensities of RGB were selected as test colors. The colors' intensities were chosen to vary in lightness by 12%, from little to full pure color. Fig. 3 presents a plot of these colors and shows how adding black ink influences the appearance of the resultant RGB colors. Except in the case of colors with full intensity (e.g., pure red, pure green, or pure blue), black ink is always noticeably present.

SOLUTION DESCRIPTION

Although CAC color palettes contain true black, true black is rarely found in the digitized aeronautical charts. It is present in CAC palettes primarily for areas of no data coverage. Since the CAC data rarely (if ever) require true black, and since the addition of black by the plotter seriously compromises the quality of many other CAC colors, the final solution to the color drop-out problem pivoted around the elimination of black ink from the plotting process.

The FORTRAN source code for the plotter software[3] was modified in-house to completely omit the inclusion of black ink: RGB intensities were converted to their CMY equivalents (Eq. 2), and the adjustment algorithm (Eq. 3) for black ink was eliminated. Fig. 4 presents the resulting test plot of RGB colors (in which intensity varies by 12% from little to pure color) using CMY inks and no black ink. The lower intensity RGB colors, which were particularly susceptible to color drop-out, are acceptable in appearance. The higher intensity RGB colors are also acceptable. Using the modified plotter software, another custom color palette plot was created. As shown in Fig. 5, the palette suffered no appreciable color drop-out, and all colors were more accurately reproduced.

CONCLUSIONS AND RECOMMENDATIONS

Results from the color experiments documented here indicate that the addition of black ink interferes with the reproduction of custom colors on some hardcopy plotters. The Navy standard CAC database was used in this study. CAC data use a standard set of 30 custom-designed color palettes, each of which consists of 240 RGB colors. The custom RGB colors in CAC data did not reproduce well on an in-house, CMYK-based, color hardcopy device that added black ink during the RGB to CMYK transformation. In particular, the addition of black ink resulted in a graying effect, termed color drop-out, in most CAC colors. Several adjustments were considered, including a shift of the colors along the achromatic axis (toward higher overall intensities), increasing the size of the pixel pattern matrix from 4 × 4 to 8 × 8 pixels, and eliminating the inclusion of black ink. The first two approaches did not adequately solve the color reproduction problems; the third approach proved to be the best solution. Since true black is rarely needed by the CAC database, and since black can approximated by blending CMY colors, the use of black ink was completely eliminated. Test plots revealed that the deletion of black ink from the RGB to CMYK transformation resulted in the successful reproduction of all CAC custom colors.

An interesting corollary to this study was the demonstrated vulnerability of plot quality to environmental and chemical factors. The quality of plot appearance was profoundly influenced by environmental factors, such as room temperature and humidity. Chemical factors relating to the toner and replenisher (i.e., age and percentage used) also affected plot quality. The adverse influence of these factors was manifested by uneven distribution and absorption of ink. Due to the significant influence of environmental and chemical factors on plot quality and appearance, reference plots are now optional on all in-house plotter output. These reference plots, which include smaller versions of the RGB and color palette plots, help identify whether a poor plot was due to color problems or to environmental/chemical influences.

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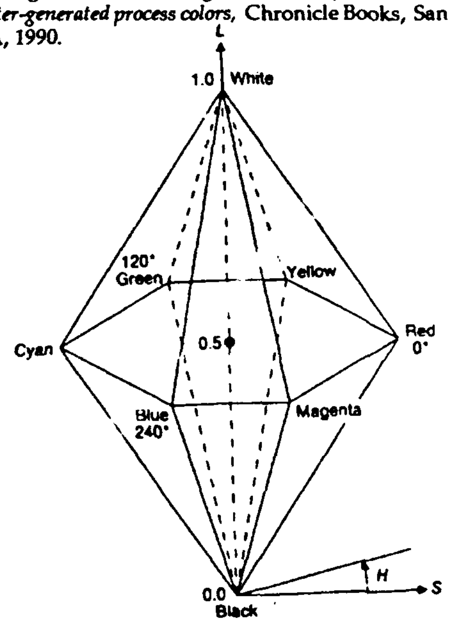

Figure 2. HLS color model.

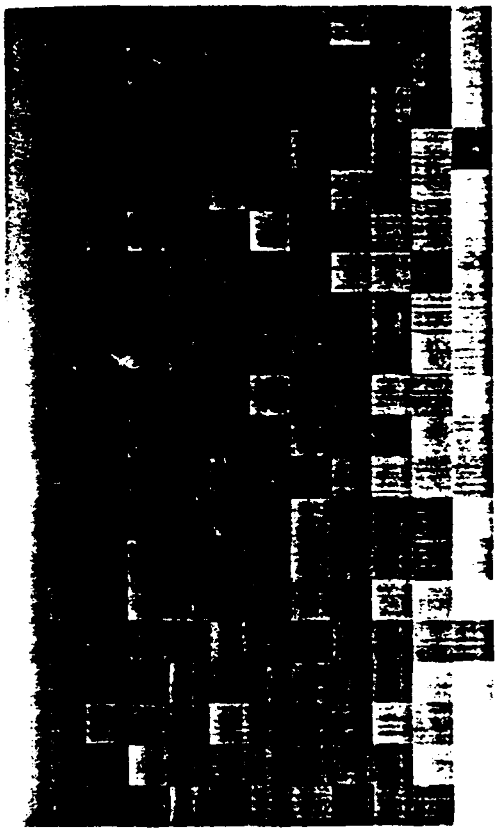

Figure 1. CAC custom color palette with color drop-out.

Figure 3. RGB test plot using CMYK inks.

Figure 4. RGB test plot using CMY inks and no black (k) ink.

Figure 5. CAC custom color palette without color drop-out.